Title: Global environmental risks of underwater acoustic data signalling: recommendations for a biofriendly underwater Internet of Things (uIoT)

Acronym: SAFE-uIoT:

1. Summary/Abstract

Underwater data communications are increasingly important for ocean science, supporting widespread use of remote and autonomous systems and sensors. Acoustic modems transmit and receive data over useful ranges underwater, as opposed to light or radio waves which are absorbed rapidly. High-rate digital communications are a norm in modern society, and international and national standards committees (ISO/IEC JTC1/SC41/WG7) are currently developing new standards for a future 'underwater Internet of Things' (uIoT). Global deployment of uIoT will entail a new input of sound into an already noisy underwater environment, leading to degradation and possible loss of habitat to marine animals, and potential impacts on human divers. To enable a sustainable uIoT system for the future, uIoT standards need to prioritize reduction of possible negative impacts of widespread use of modem sounds, shown to be aversive to seals and porpoises in captive studies. The interlinking aims of SAFE-uIoT are to assemble a uniquely skilled group of global experts to quantify the risk of negative effects to animals and humans from underwater modem networks, to engage with the standards committees to develop a bio-friendly uIoT, and to detail a longer-term research strategy to address critical knowledge gaps. The work will engage diverse international expertise and coordinate closely with existing ISO standards committees to support development of a minimally impactful (and therefore sustainable) uIoT for data signalling to support ocean science. The work will advance our understanding of how biological processes are affected by anthropogenic soundscapes, building capacity for sustainable management of the world's oceans.

2. Scientific Background and Rationale

Data signaling in an Underwater Internet of Things

Underwater data communications are a fundamental and growing infrastructure for ocean science, particularly for mobile or remote sensors or vehicles and other applications (Potter et al., 2014). Water rapidly absorbs optical and radio signals, whereas acoustic signals propagate effectively. Acoustic modems are therefore the most widely-used tool for transmitting data over usable distances underwater (Kao et al., 2017). A diverse range of commercially-available modem systems (Table 1) operate over a range of frequencies and transmission source levels, with advertised data transmission operating ranges >1km.

Historically, ocean research groups built application-specific data communication systems based upon modem manufacturer specifications. While each custom system can achieve its own task, inter-operability of underwater networks based upon agreed standards enable synergistic leveraging of hardware investments, synergistically increasing capacity and applications while reducing cost. The only international standard currently in place ("JANUS") was developed by the NATO research centre (Potter et al., 2014). Underwater IoT (uIoT) subcommittee (IOT1/SC41/WG7) was formed in 2021 (Sinha et al., 2023).

The uIoT concept envisions interconnected underwater data communication systems functioning similar to a terrestrial IoT. The key components of an uIoT are a perceptual layer of sensors and devices (such as autonomous underwater vehicles, sensors, or animal tags) that move and interact with the underwater environment collecting information, and a network layer which interconnects these digital twins of devices in the perceptual layer. The network layer links to the terrestrial internet via a surface station (a.k.a. "sink"; Domingo et al., 2012).

The network layer inherently implies a need for interlinked data transmission and reception across mobile underwater devices (Sinha et al., 2023), primarily relying upon acoustic modems. Acoustic modems within an inter-connected uIoT will transmit data packets at a sufficiently high sound level for decoding by distant receivers within a noisy underwater environment (Potter et al., 2014). The 3D location of components in the perceptual layer can be critical information because of their mobile nature, so acoustic transponder systems are often used for underwater localization (Saha et al., 2024, in press). The combination of interconnected data transmissions and transponder localization systems will increase the anthropogenic footprint of underwater noise, which could negatively impact marine life including human divers.

Table 1. A selection of commercially-available acoustic modem systems (Quackenbush. 2023, unpublished Master's thesis U of St Andrews; https://evologics.de/acoustic-modems#options and https://www.sonardyne.com/products/?_product_technology=modems).

Manufacturer	Model	Frequency (kHz)	SL (dB re 1 µPam)	Range (km)
EvoLogics	R 7/17	7-17	--	8
Sonardyne	Modem 6 Dunker 8307-1355	14-19	187-196	>5
Sonardyne	Modem 6 Standard 8307-3113	20-34	202	>5
Sonardyne	Modem 6 Mini 8244-3112	20-34	193	>3
Sonardyne	AvTrak 6 Nano 8262	20-34	175	3
Sonardyne	Modem 6 Sub-Mini 8377-1111	20-34	181	1-1.5
EvoLogics	R 48/78	48-78	--	1
EvoLogics	M HS	120-180	--	0.3

Potential for impacts on human divers and marine biota

The **frequency ranges, received sound level,** and **duty cycles** of sound sources are important factors influencing their potential for negative effects (Southall et al., 2016). For example, NATO guidelines specify a received RMS sound pressure level (SPL) limit of 154dB re1µPa to avoid harm to recreational human divers, based upon pure-tone tests over the the 600-2500Hz frequency range (NURC, 2006). The frequency range occupied by a sound relative to hearing ranges of marine biota is a starting place to identify risk of negative effects (Fig 1, right panel). The US Marine Mammal Protection Act (NOAA, 2021) predicts behavioural harassment onset at a RMS SPL received level of 120dB re 1µPa and 160dB re 1µPa for continuous (100% duty cycle) versus intermittent sounds, respectively.

Received sound levels can be measured directly near a receiving organism, or estimated as source level minus transmission loss caused by spreading and absorption. Near a source, sound spreads spherically, so spreading loss in decibels is ~$20\log_{10}$(range), e.g. 60dB at 1km distance. Absorption increases strongly with signal frequency. At a salinity of 35 ppt, temperature of 8°C, pH of 8 and pressure of 50m depth absorption is 1.0 and 26.5 dB/km at 21 and 80 kHz, respectively (Ainslie and McColm, 1998). Greater absorption at higher frequencies limits the effective ranges of modem signals (Table 1, above).

Negative effects of underwater sound on a wide range of marine biota have been reported, though effects of modem sounds have been less well studied (Duarte et al., 2021). Kastelein et al (2005; 2006) demonstrated discomfort avoidance received level thresholds to modem sounds of 97-112dB in captive harbour porpoise (Kastelein et al., 2005) and harbour seals

(Kastelein et al., 2006). Field studies of acoustic deterrent devices, in a similar frequency band as modem sounds, documented strong avoidance responses with porpoise density decreasing by 90% when sounds were active compared to control periods (Olesiuk et al., 2002). Animal presence decreased most strongly nearer the 10kHz source transmitting at 194 dB re 1µPa m source level, but avoidance likely extended beyond the maximum survey distance of 3.5 km.

Modem use is already an important component of anthropogenic noise (Duarte et al., 2021), impacting the environment over relatively long durations (Figure 1, left panel). Sounds levels within such a uIoT networked area will be elevated above background noise levels with a potential to be aversive to marine mammals, and possibly other biota. The spatial scale of modem sound exposure will increase (Figure 1, arrow in left panel) within a growing global uIoT infrastructure. Given that captive and field studies have documented aversive responses to data transmission sounds, plans for widespread deployment of modems within a future uIoT represent a hazard to marine habitats.

The characteristics of acoustic modem use within a future uIoT system (and potential associated impacts on human divers and biota) will depend critically upon the specifications of the network layer and signaling requirements within the uIoT network. For example, a more impactful scenario could result from 100% reliance on acoustic signalling, with high transmission loads due to user demand with a small number of high source level modems transmitting at low frequencies. Humans and biota interacting with such a system would experience higher received levels. A less impactful scenario could result from maximizing use of other media (cables, optic, radio) and managing user demand to reduce acoustic transmissions, with modems transmitting low source-level high-frequency signals that are rapidly absorbed. Efficient standards protocols to minimize the number of transmissions needed would reduce the sound footprint created by the system. Humans and biota interacting with such a system would be exposed to fewer signals at lower duty cycles and received levels. Initial analyses (Quackenbush, 2023, unpublished Master's Thesis, U of St Andrews) indicate that habitat effects are lower when a greater number of high-frequency modems are used, compared to fewer low-frequency modems.

<u>Need and timeliness for a SCOR working group: towards an environmentally SAFE-uIoT</u>

Our SCOR working group will bring together a diverse range of experts including IT experts, bioacousticians, risk assessment specialists, standards experts and regulators to support development of an **environmentally friendly uIoT**, ensuring that appropriate global standards are in place for future science applications. Working group efforts will improve our understanding of the biological effects of anthropogenic soundscapes, and define a future research strategy. uIoT standards are being developed now, so the timing is urgent.

Our working group is inspired by the 'well-managed future' vision of Duarte et al., (2021, see summary figure therein) to provide proactive scientific advice to design an environmentally safe uIoT (Sinha et al., 2023). This is critical for sustainable ocean science as underwater data applications will grow in the future.

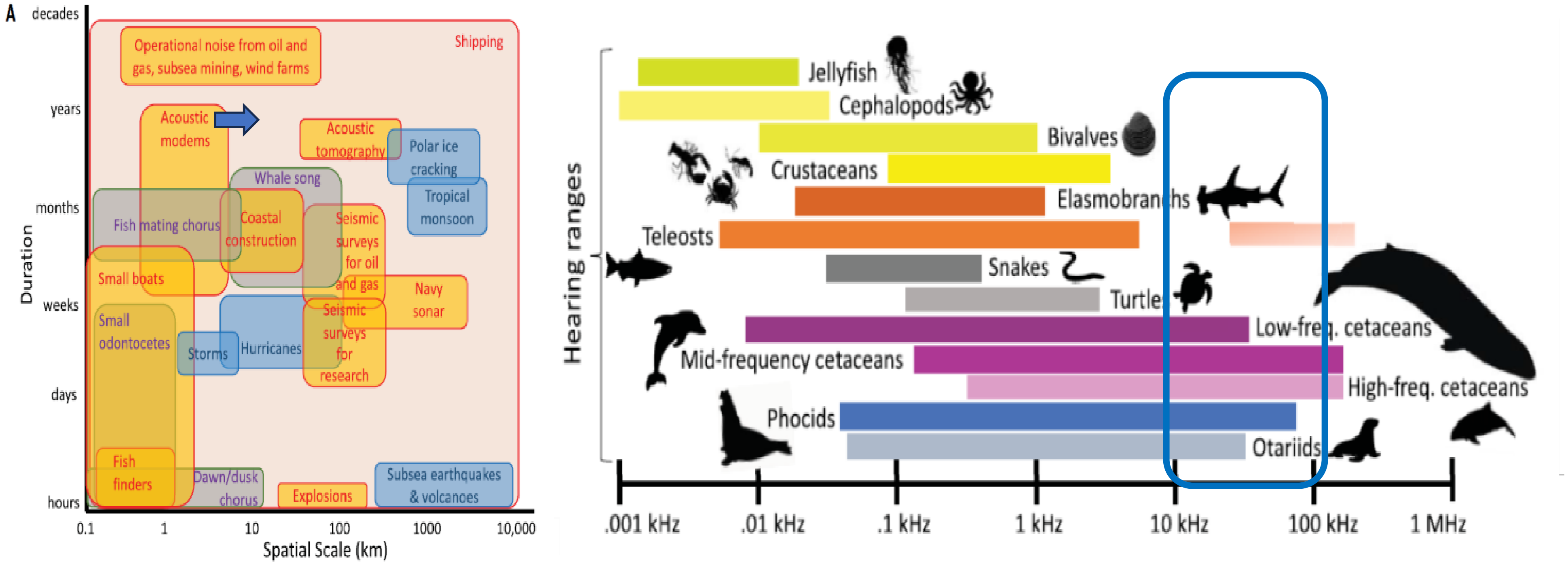

Figure 1. Left panel: spatial and temporal scale of anthropogenic and natural sounds in the ocean. The arrow indicates the expected increase in spatial scale of modem sound use within a future uIoT. Right panel: Hearing frequency ranges of diverse marine life. The box indicates the typical frequency range of acoustic modems (Table 1), indicating overlap with the hearing range of marine mammals and certain teleost fish. Modified from Duarte et al. (2021), figure 1 therein.

3. Terms of Reference (ToR)
Our proposed WG will work to achieve the following objectives:

T1. To define and publish an open access consensus paper describing the potential hazards to human divers and marine life from increased underwater noise resulting from operation of a global uIoT data network.

T2. To provide expert guidance for completion of a transparent risk assessment which will quantify how much underwater habitat is predicted to be affected by acoustic data modem use in a future underwater internet of things.

T3. To develop best-practice guidelines for system architecture, and data protocols to reduce the potential negative impacts of underwater data signaling. The goal is to develop standards that will allow all varieties of marine life to thrive while sharing their ocean habitat with a global underwater internet and communications network.

T4. To establish a Research Strategy to specify future research priorities for managing future risks of underwater acoustic signaling to divers and marine life.

T5. To build capacity both across borders and generations through mentoring of early career scientists and engaging public involvement on an international scale.

T6. To cooperate closely with representatives from regulatory agencies and standards committees to assure that advances in the working group will impact uIoT stakeholders as widely as possible.

T1-T4 are the core objectives that will lead to the deliverables. T2 and T3 will be coordinated closely with the ISO/IEC standards committees. T5 and T6 are cross cutting objectives that will apply to all of the working group's activities and outputs.

4. Deliverables

D1. **Paper describing hazards of acoustic modem use** (T1, T5, T6): Submission of an open access community paper describing the hazard related to global deployment of an uIoT modem networks due to increase in underwater noise, and possible effects on marine animals and human divers. This open-access paper will highlight information gaps required for stakeholders including industry, environmental NGOs, and regulators.

D2. **Write Technical Report** (T1-T3): Collaborate with ISO/IEC standards committees to complete a technical report that details the risks of habitat loss due to acoustic transmissions within specific underwater internet of things networks. Risks will be characterized for specific use cases, methods and datasets will be shared publicly via GitHub.

D3: **Publish papers from Technical Report** (T1-T3, T5, T6): Publish two peer-reviewed open access papers reporting the risks identified in the Technical Report. One paper to focus on effects on humans, other paper on marine life, though it is possible that separate papers will focus on marine mammals and other marine biota.

D4. **Publish Research Strategy** (T4, T5, T6): Building on the findings of the Technical Report analysis, a set of research priorities will be developed and ranked in order of priority. The research strategy will be published in a format similar to that of Boyd et al. (2008).

5. Working plan

Structured interactions will assure the objectives and deliverables of the project will be met.

1.) Plenary meetings will be held at least annually to guide ongoing WG efforts related to terms of reference and deliverables. SCOR plenary meetings will be held in association with plenary meetings of two standards committees IOT1/SC41 and ISO/TC43, held in multiple international locations to foster public participation on a global scale. All meetings will have a hybrid option to allow full participation of members not able to travel.

2.) Technical report working meetings will be held at least quarterly in association with Joint Working Group JWG 32 (joins uIoT standards committee IOT1/SC41/WG7 and marine bioacoustics standards committee ISO/TC43). Technical report meetings will be remote.

3.) Internal communications based upon chat, email and video-conferencing will support detailed progress toward project goals and finalization of deliverables.

4.) Early career researcher mentoring meetings will be held remotely at least quarterly between mentor-mentee pairs of SCOR working group members, to provide specific training and mentoring opportunities for the less-experienced members of the SCOR working group. The mentor-mentee pairs will be arranged in the first plenary meeting.

Review paper describing hazards of a global uIoT data network – T1, D1

We will review existing literature describing uIoT use-cases and design concepts, highlighting interactions with the environment. To date there has been little consideration of the potential harmful effect of extensive global acoustic signaling in a future uIoT. Review will include documented effects on human divers and marine life. The vision of a SAFE-uIoT will be introduced in this first paper, including its relevance to stakeholders including regulators and standards committees.

Risk assessment and best-practice guidelines for uIoT scenarios – T2, T3, D2, D3

A standard risk-assessment approach will be followed (Figure 2) as described in Boyd et al. (2008). The initial step of Hazard Identification of how a uIoT system might have negative effects on humans and biota will be completed in the first paper T1, D1. For other risk-assessment tasks, members of the SCOR working group (collaborating with JWG32) will be organized into four breakout groups.

Breakout group 1 - Exposure assessment is the quantification of how much acoustic modem sound energy is introduced to the environment, the area of habitat over which that exposure occurs and species within those habitats. Exposure assessment will require detailed uIoT use-cases including details of modem source levels, frequency, and duty cycle, based upon JANUS and new proposed uIoT standards. Members of this breakout group will be experts in underwater data communications, including members of standards committee IOT1/SC41/WG7, to specify how alternative uIoT standards will alter modem use.

Breakout Group 2 – Potential negative effects of exposure on individuals and populations as a function of received sound levels (dose-response assessment). This group will review and synthesise literature documenting effects (or lack of effects) of sounds on humans and marine biota, focusing on modem sounds or other sounds with similar characteristics as modem sounds (e.g. Kastelein and Olesiuk papers described in the background section). Given the frequency range of sounds to be used in an uIoT (Figure 1, right panel), marine mammals and hearing specialist fish (e.g. the clupeids) will be the key marine biota. The potential influence of non-acoustic contextual factors on the variability and severity of negative effects will be part of this task.

Breakout Group 3 - Risk characterization calculates the predicted number of animals or area of habitat negatively affected by each evaluated use case scenario. This task involves linking received sound-field maps to habitat or animal distributions (group 1) to calculate the number of animals or area of habitat negatively impacted based upon the dose-response assessment (group 2). Characterized risk will be related to management requirements such as legal protections for animals and/or the environment (e.g. US Marine Mammal Protection Act).

Breakout Group 4 - Mitigation is the key step for develop SAFE-uIoT, introducing best practice guidelines and standards to reduce the exposure to marine habitats. This step benefits from detailed knowledge of the mechanisms of how the exposure leads to negative effects (ie duty cycle or sound level), as well as how detailed uIoT standards will influence data signalling levels. Risk characterization calculations will be repeated with vs without SAFE-uIoT recommendations, to quantify the environmental benefits. The cost of specific high-data demand user applications of uIoT could be evaluated in this step.

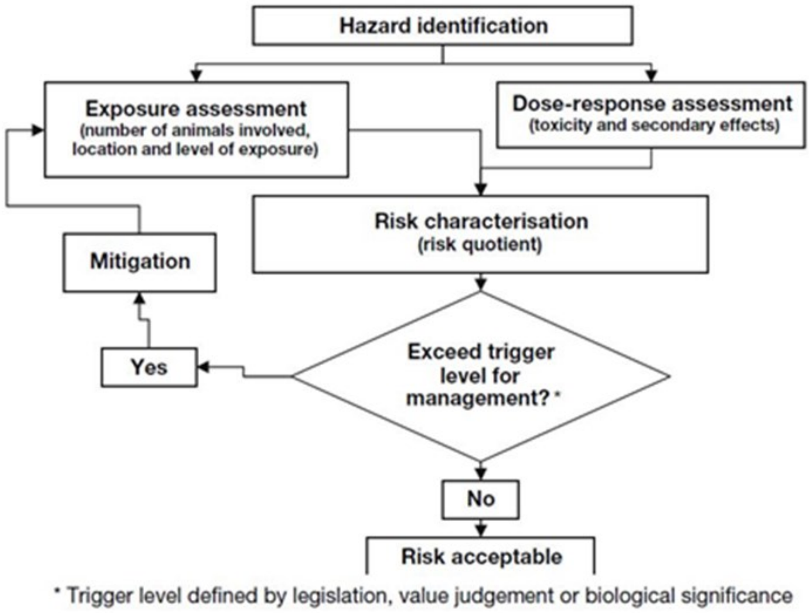

Figure 2. Risk assessment framework, taken from Boyd et al., 2008.

Consensus Research Strategy, T4, D4

During the preparation of the technical report and publications, WG members will continuously detail when knowledge gaps are identified, and each breakout group will produce an initial list of research priorities to address those gaps. A multi-day SCOR plenary meeting in Spring 2027 will collate the research priorities that will be prioritized into a research strategy following the scheme in Boyd et al. (2008). All WG members will contribute to the creation of the consensus strategy T4 and its publication D4.

Cross-cutting Terms of Reference T5, T6

Fostering development of early-career researchers (T5) and interfacing with international standards committees (T6) will be a continuous part of all WG activities. The development needs of early career researcher in the WG will be detailed in the kick-off meeting, and each early career researcher will be voluntarily paired with a senior researcher with specific skills in the area. The mentor-mentee pairs will have regularly meetings to support development and transfer of skills to mentees.

Specific activities to achieve the ToR and Deliverables are summarized in a GANTT timeline (Figure 3). The black arrows indicate information to be across the working groups focusing on T2, and across overall ToR tasks.

Figure 3. Schedule of activities for the SCOR working group.

	2024	Year 1 (2025)				Year 2 (2026)				Year 3 (2027)			
ITEM:	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Terms of Reference (T): Overaching T5 and T6 not included													
T1: Hazards paper													
T2: Risk assessment													
Breakout group 1													
Breakout group 2													
Breakout group 3													
Breakout group 4													
T3: Best-practice publications													
T4: Research Strategy													
Completion of **Deliverables**:				**D1**			**D2**			**D3**			**D4**
	kick off												
Plenary meetings:	1: Nov		2: May				3: May		4: Nov	5: Mar			6: Nov
-Linked Standards*	SC41		SC41				TC43		SC41				TC43
Mentor-mentee	pairing		meet		meet		meet		meet		meet		meet
Conference presentation:			T1			T2			T3			T4	

*SCOR Working Group plenary meetings will be associated with a standards plenary meeting, except meeting 5.

Note: the kick off meeting in November 2024 will be strictly remote if funding for in-person travel cannot be arranged in time for that meeting.

6. Capacity Building

6.1 Overview:

Our working group plan is structured to prioritize capacity building, both inter-generationally and inter-nationally, to increase the expertise base to assess and manage the potential environment consequences of uIoT into the future.

A cornerstone of our overall approach is to foster international awareness and input into underwater Internet of Things (uIoT), and how it can be developed in a sustainable way across generations and international boundaries. Because environmental management of uIoT is interdisciplinary in nature, we will foster skills across the various key skills sets including IT, marine biology, bioacoustics, risk assessment, standards and regulation. Publicly available documents and podcasts of webinars recorded during plenary meetings will reach diverse international audiences. Key WG outputs will be presented at international conferences with a global reach.

All members of the WG commit to expanding the available funding base to support the efforts of the project, from within their own institutions', industry, research agencies, and philanthropic institutions. Funding requests will be focused on enabling capacity building for students and international participation by citizens of less-developed countries.

6.2 Inter-generational capacity building:
The underwater Internet of Things (uIoT) will be a global feature of future life on earth, so a key part of our WG goals is to develop skills in junior researchers and students to address this issue in the future, after our working group has finished.

Within our working group, Capacity Building intergenerationally will be achieved by supporting skills development in early career researcher members of the working group. This will be accomplished by linking a junior member (mentee) with a specific more senior member (mentor). For example, one ECR member of our full committee Dr Viana from Brazil completed her PhD in 2023 with a thesis entitled "Alterations in the acoustic production of odontocetes across co-occurrence contexts." She is highly knowledgeable in her field of marine bioacoustics, but is still working to publish key papers and has less experience with uIoT and related environmental risks of uIoT than more experienced members. Dr Viana will be linked to a more senior mentor to create a direct and focused mechanism to support individual developmental needs of junior members. All 4 of the ECR members of our working group (plus others who self-identify as needing mentoring) will become a mentee within a mentee-mentor pair, to foster and develop their specific skills, so they will become future leaders in this area. Two dedicated mentor-mentee meetings per year are scheduled in the timeline.

Outside of the working group, intergenerational capacity building will be fostered by bringing in Master's and PhD students to work on the project. SCOR WG chair Miller and Full member Sinclair commit to support the involvement of Master's students over the course of the WG. They have an established track record, already having co-supervised the Master's research of Associate member Alyssa Quackenbush at the University of St Andrews in their renowned Master's program in Marine Mammal Science. SCOR WG member will be offered roles as collaborators to further support Master's research students. Additionally, Miller and Sinclair will apply for a World-Leading Scholarship for a PhD in biology in November 2025 see: https://stleonardscollege.st-andrews.ac.uk/world-leading-scholarships-2024-2025/. Other working group members will also be encouraged to involve research students in the project.

6.2 Inter-national capacity building:
The underwater Internet of Things (uIoT) is envisioned as a global phenomenon which will affect all parts of the world. Therefore, a key goal of this working group is to increase exposure and participation globally. Our SCOR working group has a diverse international makeup including members from 9 countries across 6 continents. Two full members are from developing nations (China, Brazil), and one from an underdeveloped nation (Mozambique). Though this is a start to global participation in solving the uIoT challenge, it is clear that significant efforts are needed to increase international awareness of, and participation towards solving, this issue.

As our SCOR working group is international, we will conduct outreach events in locations where we hold plenary meetings, including recording and publication of a webinar podcast alongside a press release in the host country. By this means, we hope to increase direct contact with citizens of the diverse countries that will host our meetings (China and Canada are currently planned locations). Where possible, we will lobby for plenary meeting to be held in less developed countries, to increase international exposure of the project.

The global nature of the uIoT development is reflected in the fact that global standards are being addressed within ISO standards committees. A key avenue by which our SCOR working group will expand international engagement will be via fostering increased international engagement in the SC41 standards committee, tasked with developing global standards for the uIoT. At present, a total of 41 countries are formally member of ISO/SC41 in some capacity. See: https://www.iec.ch/dyn/www/f?p=103:29:::::FSP_ORG_ID:20486. We will encourage global participation in SC41 in several ways: To increase SCOR WG members to encourage their nations to join SC41. For example, Mozambique and Brazil are not currently participating in SC41 so members from those countries will lobby for formal involvement in the ISO process.

The WG will identify nations that have the potential to be affected by a future uIoT, but that is not involved in the SC41 standards effort. For example, Angola has an extensive coastline rich in marine life which also supports industry – yet Angola is not formally involved in the ISO SC41. After developing the list of key countries not involved in SC41, WG members will be tasked to search their networks for appropriate contacts, in research industry or government, in those countries. By engaging these contacts, we will expand international awareness of the need for management of underwater data communication networks, encourage active participation by citizens of all nations, and promulgate globally the recommendations stemming from our WG efforts.

7. Working Group composition

The working group consists of experts in underwater IT, bioacousticians, risk assessment specialists, standards experts and regulators. These include all the key skillsets needed to accomplish the ToR and Deliverables of the Working Group. they have been allocated evenly across the 4 breakout groups, with higher involvement in BG4 which links to **ToR 3**.

The full set of 17 members are working in 9 countries on 6 continents, including 1 from a country with an underdeveloped economy (Mozambique), and 2 countries usually classified as emerging/developing economies with upper-middle (China, Brazil). Early career researchers make up 24% of our working group members, with 2 among the Full members and 2 among the Associate members. Our WG is gender balanced with 8 female and 9 male members overall, with 5 female and 4 male Full members, and 3 female and 5 male Associate members.

The expertise of the SCOR working group will be augmented by input from the related ISO standards committees for creation of the risk assessment Technical Report **D2.** The chair of JWG 32 (Matara), the technical report lead Editor (Schoechle) and co-Editors (Miller, Matara, Nissen) are members of the SCOR working group. Our SCOR working group will follow terminology published in ISAO 18405.Terminology standards will be supported by SCOR Full WG member Michael Ainslie, who is the chair of standards sub-committee ISO/TC43/SC3/WG2 on terminology.

Full Members (no more than 10, please identify chair(s))

Name	Gender	ECR?	Nation	Expertise relevant to proposal Breakout Group involvement
Patrick Miller, chair	M		UK	Effects of noise on marine mammals; BG 1, 2, 3, 4
Darlene Ketten	F		USA	Hearing of marine mammals BG 2, 4
Songhai Li	M		China	Marine bioacoustics BG 2, 4
Amy Scholik-Schlomer	F		USA	Regulation of protected species, fish acoustics BG 2,4
Ivor Nissen	M		Germany	Underwater data networks BG 1, 4
Rachael Sinclair	F	Y	UK	Risk assessment of noise sources BG 3, 4
Yasmin Viana Pinto	F	Y	Brazil	Marine Bioacoustics. BG 2, 3
Charlotte Curé	F		France	Bioacoustics, effects of noise BG 2,4
Michael Ainslie	M		Netherla nds	Marine acoustics, bioacoustics terminology standards. BG 3

Associate Members

Name	Gender	ECR	Nation	Expertise relevant to proposal Breakout Group involvement
Kathy Matara	F		USA	Standards JWG chair, environmental champion BG4
Timothy Schoechle	M		USA	Standards committee BG 1
Michael Stocker	M		USA	Effects of noise BG4
Justin Dinale	M		Australia	Military application of underwater data networks BG 1,4
Victorine Lambert	F	Y	France	Literature review of effects of noise. BG 2
Alyssa Quackenbush	F	Y	USA	Masters Research on risk assessment framework BG 3
Thomas Daniel	M		USA	Ocean measurements and instrumentation BG 1, 4
Dennis Peter Faisca Guiamba	M		Mozamb ique	Oceanographic research and blue economy at: Instituto Oceanografico de Mozambique BG 2, 4

8. Working Group contributions

Below is detailed the key expertise of each Full Member. See the member table for the Breakout Group involvement of each Full and Associate Member.

Patrick Miller has published multiple studies on the effects of underwater noise on marine life (Miller et al., 2024), and contributed to the 2008 European Science Foundation position paper on effects of sound on marine mammals (Boyd et al., 2008). He has key expertise across all activities of the WG, and can dedicate time to accomplish the goals of the WG.

Darlene Ketten has key expertise in the hearing abilities of marine organisms, effects of noise on marine mammals, and nomenclature standards for marine bioacoustics. She will contribute critically to the task of identifying which marine biota are at risk of negative effects from modem sounds.

Songhai Li is an expert on the natural behaviour and ecology of marine mammals. He will contribute particular expertise to identifying habitat use of marine mammals, including in the South China Sea area.

Amy Scholik-Schlomer is an expert on fish hearing, and works for the USA regulatory agency NOAA. She will provide biological knowledge for fish taxa potentially at risk from modem sounds and a strong linkage to regulatory aspects of the WG tasks.

Ivor Nissen is an expert on underwater data signalling, and one of the originators of the existing JANUS standard for underwater communication. He will provide key expertise for detailing use cases of how uIoT applications will lead to specific levels of acoustic signalling.

Rachael Sinclair is an expert on risk assessment of underwater noise sources, with a wealth of experience highly directly related to all of the tasks of the WG. She will contribute broadly across the entire effort, but particularly for the risk-assessment ToR.

Yasmin Viana Pinto is an expert on acoustic ecology of marine mammals, and is working on a project assessing the potential impacts of sounds used in seismic prospecting. She will contribute critical skills about how underwater modem sounds might impact marine mammal communication.

Charlotte Curé is an expert in bioacoustics with a track record documenting effects of sound on cetaceans, and their biological significance. She will contribute to acoustic modelling of sounds sources and their predicted impact on marine mammals in the affected habitats.

Michael Ainslie is an expert in marine acoustics and terminology standards. He provides unique expertise for predicting sound fields generated by modem networks and a key linkage in the project to ISO standards committees for marine bioacoustics.

9. Relationship to other international programs and SCOR working groups

Our proposed WG will make key contributions towards the United Nations 10 Challenges Ocean Decade Challenges for collective impact. see https://oceandecade.org/challenges/ Our work will benefit: Challenge 1 by addressing how to understand and manage the noise pollution created by uIoT, Challenge 2 by developing solutions to protect and manage ecoystems, Challenge 7 of expanding the global ocean observing system in a sustainable fashion, Challenge 8 of creating a digital representation of the ocean, and Challenge 10 to change humanity's relationship with the ocean.

As detailed above, Terms of Reference 2 and 3 as well as Deliverable 2 of this WG are very closely aligned with two global ISO committees working on international standards of relevance to uIoT. The technical report (Deliverable 2) is a specific task of an ISO joint working group (JWG) 32 which links two different committees IOT1/SC41/WG7 (underwater Internet of Things) and ISO/TC43 (Marine Bioacoustics). All SCOR WG members will be invited to participate in JWG32 meetings, and 10 of 14 SCOR WG members are already formally affiliated with one or both standards committees.

Our proposed WG overlaps in subject area with the International Quiet Ocean Experiment (IQOE), which benefitted from support from SCOR, including hosting of a 2011 workshop. Chair **Miller** of the current proposal was involved in the 2011 workshop, which led him to develop the idea to submit this current proposal to SCOR.

Our WG overlaps in scope with some previous working groups, including WG 96 Acoustic Monitoring of the World Ocean which focused on acoustic methods to study ocean climates and WG 133 OceanScope which focused on underwater data communications. Our WG efforts will benefit from the current efforts of SCOR WG 169 which is developing a global library of underwater sounds.

Key References cited: Names of members of the working group are bold and underlined

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Appendix: Five publications for each Full WG member:

Patrick Miller (Chair)

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Dr Viana is an ECR with the following papers to be submitted before July:

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